APPENDIX G6

AGRICULTURAL PRODUCTION AND ECONOMICS

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Acronyms/Abbreviations

AF	acre-foot or feet
dS/m	decaSiemen(s) per meter
EC	electrical conductivity
ET	evapotranspiration
ppm	part(s) per million
TDS	total dissolved solids
Unit	San Luis Unit
Westlands	Westlands Water District

G6.1 AFFECTED ENVIRONMENT

The San Luis Unit (the Unit) is predominantly an agricultural region, comprising four water districts that hold contracts for Central Valley Project water. Westlands, Broadview, Panoche, and Pacheco water districts, and the southern portion of San Luis Water District, cover about 713,000 acres. This area is one of the most productive farming regions in the United States, and can continue to be with adequate Agricultural Production and Economics water supply and drainage.

Recent data compiled from district reports, the Bureau of Reclamation crop reports, and California Department of Water Resources crop surveys indicate that irrigated crop acreage can range up to nearly 550,000 acres in Westlands Water District (Westlands), depending on water supply and market conditions. In the four Northerly Districts, irrigated acreage has averaged about 80,000 acres in recent years. Not all of this land is in the potentially drainage-affected area as defined for this report.

A wide variety of crops are grown in the Unit. Table G6-1 summarizes the cropping pattern for the two portions of the Unit. The distribution of crops is not uniform within the districts. For example, orchards and vineyards tend to be grown in well-drained and upland areas of both Westlands and the four Northerly Districts.

Table G6-1
Irrigated Land Use in the San Luis Unit

Major Crop Type	Percent of Irrigated Area, Average from 1995–1999	
	Westlands	Northerly Districts
Forage	3	10
Cotton	45	48
Grain	6	3
Sugar Beets	1	1
Other Field	1	2
Tomatoes	17	12
Truck	19	22
Orchard/Vineyard	7	2
Total	100	100

Source: District crop reports, various years.

Over 30,000 acres of land in the Northerly Districts have subsurface drains installed and operating. These lands discharge drainwater to the Grassland Bypass. An additional 18,000 acres of drained land outside the Unit also discharge drainwater to the Grassland Bypass. Drains have also been installed on approximately 5,000 acres within the northern portion of Westlands, and these operated up until 1986.

G6.2 ENVIRONMENTAL CONSEQUENCES

G6.2.1 Evaluation Criteria

The objective of drainage service is to provide soil and shallow groundwater conditions that will allow long-term agricultural production. The purpose of this section is to assess and compare how well the alternatives achieve that objective. The following evaluation criteria are addressed:

- Volume and salinity (total dissolved solids [TDS]) of drainage collected;
- Salinity of the crop root zone, defined for analytical purposes as the top 6 feet of soil;
- Salinity of shallow groundwater;
- Overall salt balance in the drainage-affected area;
- Crop acres in production;
- Potential crop yields and revenues as determined or limited by soil salinity; and
- Farm-level costs of irrigation and salinity management.

G6.2.2 Evaluation Approach

A modeling approach developed for this study assesses how drainage conditions under different alternatives affect root zone salinity, crop yields, crop production costs, and drainage quantity and quality. The APSIDE model combines components from several pre-existing models. The economic crop production submodel within APSIDE is an adaptation of the SWAP model developed at University of California Davis. It uses a hybrid estimation and optimization algorithm to predict the optimal mix of crops, water use, and other input decision under conditions of limited water supply and/or saline growing conditions. The economic submodel estimates crop production functions using five inputs: land, water, capital, labor, and land quality. The land quality input is derived from the well-known Maas-Hoffman relationships between soil salinity and crop yields. Soil salinity estimates are provided through the linkage of the crop production submodel to a drainage and salinity submodel.

The drainage and salinity submodel is adapted from the IRDROP (Irrigation and Drainage Operations) Model developed, tested, and used for the 1990 San Luis Unit Drainage Program (Reclamation 1990). The model simulates changes in soil moisture and salinity, shallow groundwater volumes (levels) and salinity, and drainage flow and salinity over a user-defined number of years. Key input data affecting the resultant estimates include crop water use, salinity of applied irrigation water, naturally occurring drainage (movement of water out of the shallow water table in the absence of artificial drainage), effective conductance of groundwater into artificial drains, and starting levels of salinity in shallow groundwater.

Importantly, the drainage and salinity submodel is able to simulate both the upward movement of water and salts from shallow groundwater and the downward movement of water and salts from the percolation of applied irrigation water. The interaction of these two processes determines the long-term trend in soil salinity and crop productivity. The submodel also incorporates a set of relationships that account for the precipitation and dissolution of gypsum and similar compounds. A simple approach developed by Aragues et al. (1990) was used that assumes that the saturation solubility of gypsum produces a fairly constant base load of dissolved salts in the soil water and shallow groundwater.

A third submodel within APSIDE is a set of calculations for deeper groundwater conditions and flows. This submodel is not being used for San Luis Unit plan formulation. Instead, an existing MODFLOW model developed by the USGS (see Appendix G1) is used to estimate regional changes in groundwater conditions, including changes in the depth to shallow groundwater and the rate of net outflow from the shallow groundwater (also referred to above as natural drainage).

The modular nature of APSIDE allows the submodel components to be used interactively or individually.

Figure G6-1 shows how the submodels interact. APSIDE is written in the GAMS (Generalized Algebraic Modeling System) computer language, but a spreadsheet version of the drainage and salinity submodel has also been developed to provide rapid and more transparent screening and assessment of alternatives. Calibration and testing of the crop production submodel was continuing during the preparation of this Plan Formulation Report. Therefore, evaluation results described below were made using the salinity and drainage submodel and an external evaluation of crop yields and production costs. It is expected that the crop production submodel will be available for subsequent environmental and economic impact analysis.

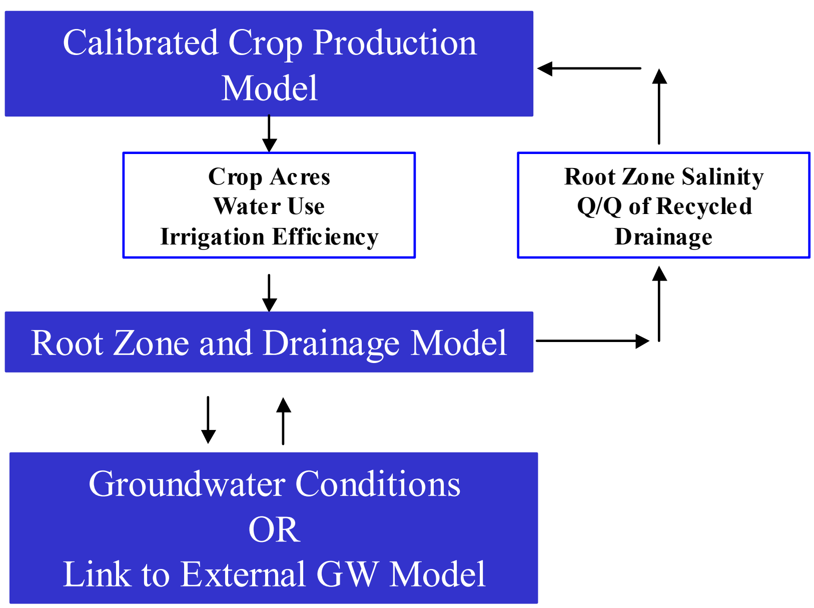


Figure G6-1 Schematic of the Analytical Components of the APSIDE Model

G6.2.3 No Action Alternative

G6.2.3.1 Northerly Districts Subarea (San Luis Unit portion of the Grassland Drainage Area)

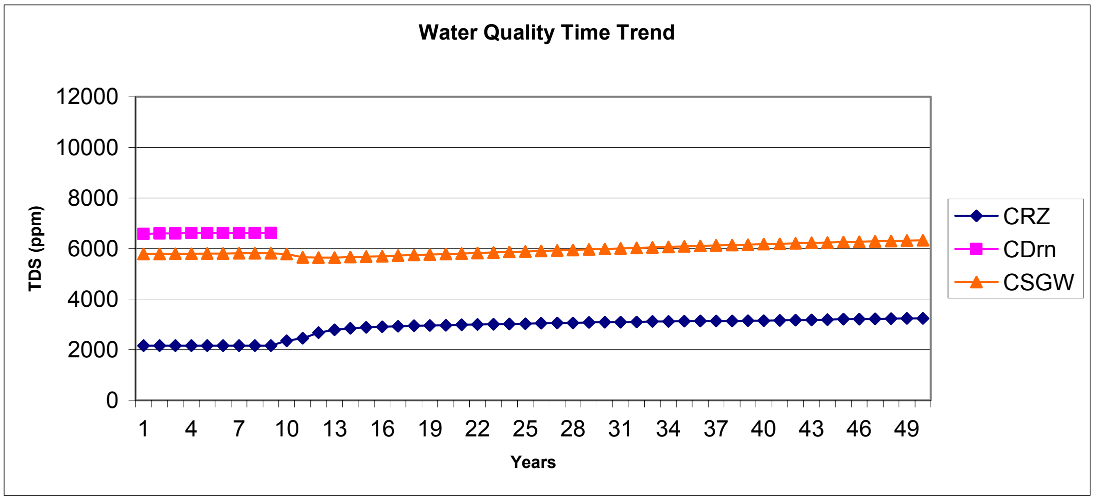
Key Assumptions

The following assumptions are used to analyze agricultural production and economics under the No Action Alternative:

- Under current conditions (1997–1998 data collected from the Grassland Bypass Project monitoring program), the average drainage generated is about 0.75 acre-foot(AF)/drained acre/year. Of this amount, 20 percent, or 0.15 AF/drained acre is blended into irrigation water recycled within the drained area. Under the No Action Alternative, irrigation efficiency improves over time, consistent with projections made by the California Department of Water Resources (Bulletin 160-93 and unpublished supporting data, 1994). As a result, the drainage rate per drained acre in the Northerly Districts Subarea will be reduced to 0.6 AF/acre/year.
- The estimated reduction in drainage rate from 0.75 to 0.6 AF/acre does not imply that constituent loads requiring disposal also decline by a proportionate amount. For purposes of analysis, it is estimated that 20 percent of drainage volume (0.12 AF/drained acre) would still require recycling in order to meet the load restrictions on discharge. For analysis, the drainwater is assumed to be recycled on all lands within the drainage-affected area, not just lands with installed drains. This assumption implies that 0.085 AF of drainwater/acre would be applied as irrigation water within the drainage-affected area.
- Drains are installed at an average depth of 7.5 feet.
- The shallow water table under drained fields can be maintained within 1.5 feet above the depth of installed drains.
- The Grassland Bypass Project will continue to operate until the year 2009. After that, no drainage access to the San Joaquin River will be available for this area. Two assumptions are assessed regarding the response of growers in the drained area:
    1. Drains are plugged and no further drainage is collected. The shallow water table continues to build up under the cropped land, increasing the upward movement of salts into the root zone. Levels of irrigation management must improve to reduce deep percolation yet maintain leaching of salts.
    2. Drains continue to operate, but all drain flow must be recycled within the drainage area. The shallow water table is controlled by continued operation of drains, but irrigation water applied is significantly saltier due to the mixing of recycled drainwater with the normal water supply.
- 30,000 acres of tile drains are currently installed in the Unit portion of the Grassland Drainage Area, and another 18,000 acres are installed outside the Unit. Assuming all land stays in production (one of the objectives of the modeling analysis is to assess this), total subsurface drainwater produced would be about 29,000 AF/year, of which 18,000 AF would come from the Unit lands.

Results

Under current conditions, with drainage discharge to the Grassland Bypass, the salt balance and soil conditions are faborable for crop production. Drainage volume collected from field drains is estimated to be approximately 29,000 AF, including drainage from within and outside the Unit. However, when the Bypass is shut (by assumption), conditions worsen quickly and significantly. Figure G6-2 shows a 50-year trend in the root zone and shallow groundwater salinity for a representative drained area in the Northerly Districts. The jump in soil salinity is quite clear in year 9 and later, and results from the loss of drainage and rise in the water table below those lands.



CRZ = Concentration of salts in the root zone (ppm TDS of saturation extract)
CDrn = Concentration of salts in drainwater or potential drainwater (ppm TDS)
CSGW = Concentration of salts in shallow groundwater (ppm TDS)

Figure G6-2 Salinity Trends in the Northerly Districts Subarea Under the No Action Alternative

The figure shows the result under the assumption that the drains are plugged; the salinity increase is even more pronounced under the assumption that drains continue to operate but that 100 percent of the drainwater has to be recycled. Soil salinity is typically measured as the electrical conductivity (EC) of a saturation extract in decaSiemens per meter (dS/m), and the ultimate root zone salinity shown corresponds to an EC of over 4.6. At this level, the mix of crops that can be grown narrows significantly (see summary Table G6-5).

Because drainage is no longer provided after year 9, soil salinity would rise and net deep percolation would be limited to the small amount of natural drainage that exists. A combination of crop mix changes and irrigation management would be needed to maintain land in production. Crop changes can accomplish two objectives: they can reduce or eliminate crops that are sensitive to saline soil conditions; and they can reduce the overall level of water use and therefore the deep percolation needed for salt leaching. An appropriate mix of grains, cotton, and salt-tolerant field and row crops can meet these criteria. This analysis has assumed that an average crop evapotranspiration (ET) of 2.6 AF/acre or less can be achieved. At that level of ET, irrigation management must achieve the equivalent of 86 percent seasonal application efficiency (measured here as crop ET of applied water divided by total applied water). A further discussion of the implications of irrigation management in the No Action Alternative is included below in the analysis for the Westlands subareas.

Substantial costs would be required to implement the irrigation systems and management necessary to reduce net deep percolation. Costs are estimated as the combination of system hardware and management needed to achieve the required levels of deep percolation, application uniformity, and leaching. Results are summarized at the end of this section, and are presented as benefits (avoided costs) provided by drainage service. (Note: still pending are a refinement of irrigation costs and an evaluation of whether growers would be willing and able to pay them, or would instead remove lands from production.)

Salt balance in the Northerly Districts is favorable during the initial years when drainage is discharged through the Grassland Bypass to the San Joaquin River. Over 18,000 AF of drainwater at an average salinity of about 6,600 parts per million (ppm) TDS is discharged, removing more than 160,000 tons of salt annually from the area. Additional salts would migrate more slowly from the area through groundwater pathways, but no estimate of this amount has been made. After the closure of the Bypass in 2009, no salts would be removed through artificial drainage.

G6.2.3.2 Westlands Water District

The drainage-affected area within Westlands has been divided into three subareas as shown on Figure 2.1-1. Many of the assumptions described below apply to all three of the subareas. Where differences exist, those are noted.

Key Assumptions

The following assumptions are used to analyze agricultural production and economics under the No Action Alternative:

- No drainwater is currently being collected and removed from Westlands. The No Action Alternative assumes that this situation will continue. Irrigation efficiency in Westlands is currently quite high and is expected to remain so over time, consistent with projections made by the California Department of Water Resources (Bulletin 160-93 and unpublished supporting data, 1994). Additional changes in efficiency needed to manage irrigation in the drainage-affected area may result from the analysis.
- Shallow water table depth will continue to be a concern in substantial areas within the district. The changes in depth to water and the acreage affected by shallow groundwater will be based on groundwater modeling analysis (see Appendix G1).
- Cropping patterns are assumed to be consistent with the current mix of crops. The analysis will assess how future drainage and salinity conditions in the drainage-affected area will affect crop selection.
- Irrigation water in the drainage-affected area is a mix of surface supplies and groundwater. The mix can vary considerably between fields or farms, from year to year, and even within a year. For purposes of analyzing the long-term trends in salinity, irrigation water is estimated to be 88 percent surface water and 12 percent groundwater. The resulting salinity of applied irrigation water is about 530 ppm TDS.

- A total of about 68,000 acres will be retired in the drainage-affected area of Westlands as part of a settlement agreement between growers and Westlands (see Section 5). The exact location of these lands is not yet known. For purposes of analysis, they are distributed proportionately among the three subareas. Table G6-2 summarizes the lands retired and those remaining under irrigation.

Table G6-2
Lands Assumed Retired in the No Action Alternative

Westlands Subarea	Total Irrigated (Existing Conditions)	Acres Retired	Acres Potentially Remaining in Production
North	119,880	21,645	98,235
Central	127,260	22,975	104,285
South	129,490	23,380	106,110

Note: Lands outside the drainage-affected area are not included.

The assumptions above should be viewed as the "starting point" for analysis of the No Action Alternative. The analysis may ultimately lead to different conclusions. For example, the assumed land in production represents a potential level, that is, land not formally retired under a retirement program. Analysis may ultimately project that additional lands are taken out of production due to salinity impacts.

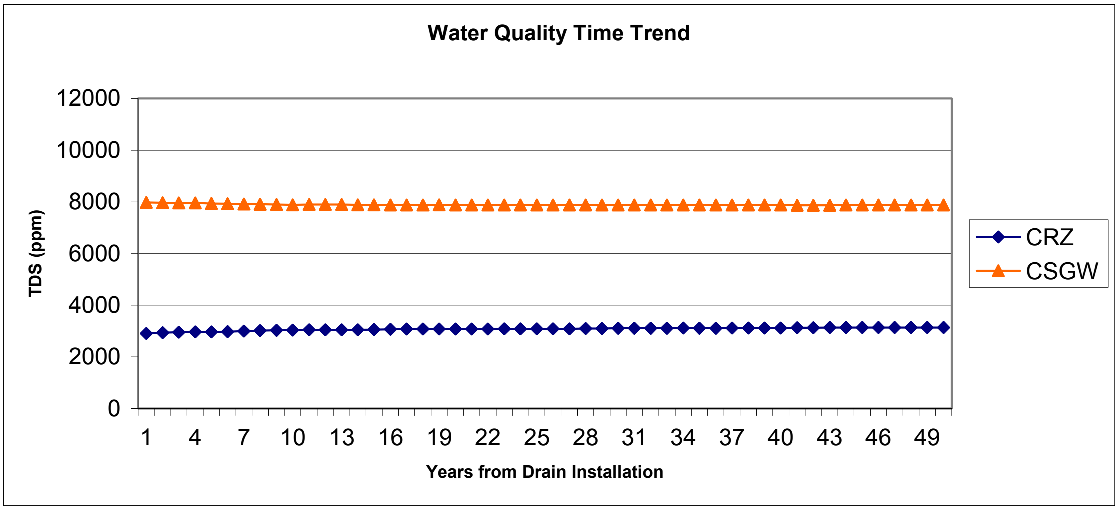
Results

The key issues for the Westlands subareas under No Action are whether lands can stay in production given the small level of natural drainage, and if so, at what cost. The evaluation follows closely what was described above for the Northerly Districts after closure of drainage to the Grassland Bypass. The natural drainage rate was estimated by regional groundwater modeling for the drainage-affected areas in Westlands. The rate declines over time, dropping to an average of about 0.25 AF/acre/year by 2030. This is a regional average for the drainage-affected lands, so there is likely to be some land with greater natural drainage and some with less.

As described for the Northerly Districts, two strategies can be used to reduce deep percolation to a level that does not exceed the natural drainage rate. First, crop mix can be changed to reduce overall water use. Second, irrigation management and application uniformity can be improved to reduce the deep percolation of applied water. Both strategies must be implemented in a way that can maintain adequate leaching of salts, or at least provides enough leaching to avoid rapid deterioration of soil conditions. Under the No Action Alternative, no salts are removed from the irrigated area through artificial drainage; consequently, they continue to accumulate in the soil and groundwater.

Results for the three drainage-affected subareas (North, Central, South) in Westlands are similar. The main difference is in the estimated starting salinity in shallow groundwater. Figure G6-3 shows estimated salinity conditions for the North drainage-affected subarea in Westlands. Conditions appear to remain relatively stable over the 50-year horizon, but at a soil salinity level that substantially restricts crop mix and profitability.

As was described for the Northerly Districts, salt balance is not achieved in Westlands under the No Action Alternative. Although Figure G6-3 appears to show a balance in salt concentration, in fact a substantial mass of salt continues to percolate below the shallow water table into the deeper groundwater layers. In addition, the No Action Alternative does not provide any outlet for removing the salts that have accumulated in the soil and groundwater from past irrigation. Conditions under the No Action Alternative would be similar for the Central and Southern subareas in Westlands.



CRZ = Concentration of salts in the root zone (ppm TDS of saturation extract)
CSGW = Concentration of salts in shallow groundwater (ppm TDS)

Figure G6-3 Salinity Trends in the Westlands North Subarea Under the No Action Alternative

Discussion of Irrigation Management

The evaluation of seasonal application efficiency to maintain land in production without artificial drainage depends critically on the estimated rate of natural drainage. Natural drainage is defined here as the annual net downward (or lateral) movement of shallow water table. Poorly drained lands have a low rate of natural drainage. If aggregate deep percolation can be kept equal to or less than natural drainage, and the deep percolation provides an acceptable leaching fraction, then long-term root zone equilibrium can be maintained. Several considerations are important for managing irrigated crop production under poor drainage conditions:

- Even if irrigation can be managed to hold deep percolation equal to natural drainage, salts will continue to accumulate in the shallow groundwater. These salts will also continue to migrate into deeper groundwater over time. Only artificial drainage that removes and disposes of salts can improve the long-term salt balance that includes both root zone and groundwater salt loads.
- Very careful irrigation management is required. This means that both seasonal application efficiency and distribution uniformity must be high. The cost of irrigation hardware and management is significantly higher than for irrigation under well-drained conditions.

- Lands for which revenues cannot support the higher irrigation and management costs will go out of production.
- The continued accumulation of salts in the shallow groundwater makes this situation relatively risky. Small changes in the overall water and salt balance (for example, reducing groundwater pumping that provided some portion of the natural drainage, or a change in the salinity of applied water) can result in a fairly rapid deterioration of root zone conditions.
- To keep deep percolation within the limits provided by natural drainage, the cropping pattern generally needs to be restricted to lower-ET crops. Small grains (e.g., wheat and barley) may need to play a larger role in the crop mix. Sugar beets and some forage crops can tolerate the saltier soil conditions, but their relatively high water uses may result in more deep percolation than allowed by drainage conditions.
- The net result of higher soil salinity and restricted deep percolation is a crop mix that excludes both salt-sensitive crops and high water-using crops. Small grains, salt-tolerant field crops, and a mixture of cotton with grains and field crops are the most feasible cropping systems.

The benefits of the drainage alternatives can be estimated as the costs avoided relative to the No Action Alternative. These avoided costs fall into three categories:

- Irrigation management costs;
- Net revenue losses resulting from the restricted crop mix; and
- Net revenue losses from land retired.

Lands for which revenues cannot support the higher irrigation and management costs will go out of production.

Interaction between Land Retirement and Irrigation Management

In the No Action Alternative, it is estimated that about 68,400 acres of land are retired within the drainage-affected area of Westlands. Land retirement has two effects on regional drainage conditions. First, it removes drainage-affected land from production and, therefore, eliminates the need to provide artificial drainage on those lands. Second, the reduction in irrigation and deep percolation of irrigation water may provide some regional benefit to the shallow groundwater: lands remaining in production may benefit, because the regional water table may be lowered to some degree due to retirement. The magnitude of this second effect has not been quantified, although groundwater analysis has estimated it to be small. The net result of land retirement and irrigation management is depicted in the impact analysis for the No Action Alternative, but the impacts cannot be apportioned between land retirement and irrigation management. It is possible that with no land retirement irrigation management would have to be even more stringent and costly (or it may simply be infeasible). Similarly, a higher level of land retirement could allow a somewhat lower level of irrigation management and crop changes in order to maintain land in farming.

Sensitivity Analysis on Natural Drainage Rate

The natural drainage available to lands in the drainage-affected area is small but significant. For the Northerly Districts it is estimated to be about 0.23 foot/year under the No Action Alternative in 2030; the corresponding estimate for the Westlands drainage-affected lands is 0.25 foot/year. These are regional averages estimated using a calibrated groundwater model (see Appendix G1). Actual conditions are likely to vary around the estimated average, resulting in some lands having more restricted drainage and some lands having less restricted drainage. In order to illustrate how small changes in the natural drainage rate can affect conditions, the APSIDE model was used to estimate the required net deep percolation and the resulting soil and shallow groundwater salinity over time under a range of assumed natural drainage rates. For illustration purposes, conditions in the North subarea of the Westlands drainage-affected area are used, but general conclusions apply for the other areas. Also, crop mix is held constant and regional shallow groundwater trends are assumed to be the same as for the No Action Alternative.

Table G6-3 summarizes the required average irrigation efficiency (defined here as seasonal ET of applied water divided by seasonal applied water) to maintain stable water table conditions. Natural drainage rate was varied between 0.1 and 0.3 foot/year.

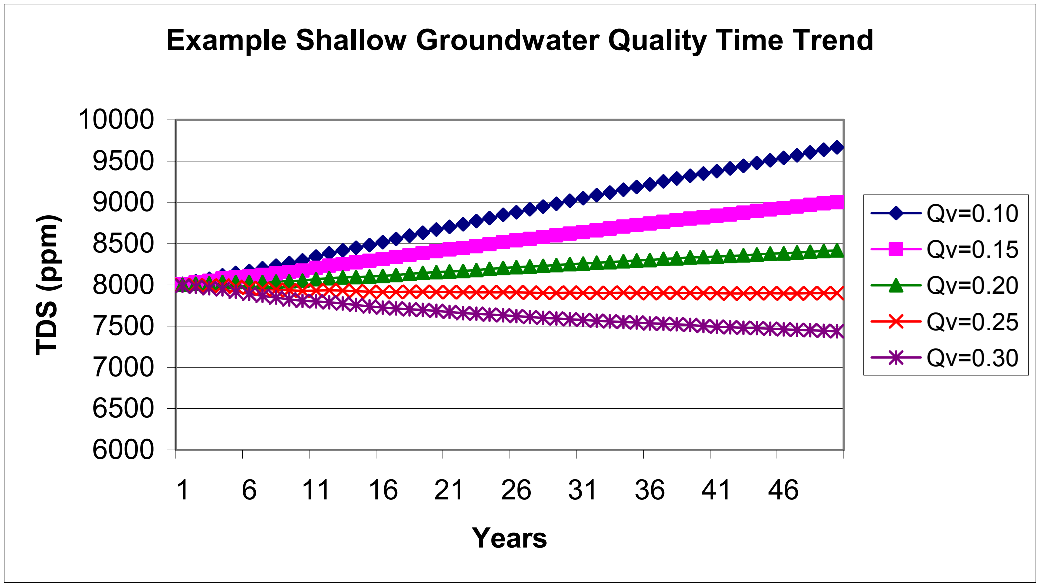
Table G6-3
Sensitivity Analysis on Natural Drainage

Natural Drainage (feet/year)	Applied Water (feet/year)	Necessary Seasonal Application Efficiency[1]	Estimated Salinity after 50 Years	
			Soil Salinity (EC)	Shallow GW Salinity (EC)
0.10	2.44	92%	4.9[2]	12.5
0.15	2.49	90%	4.6[2]	11.6
0.20	2.54	88%	4.3[2]	10.9
0.25	2.59	86%	4.1[3]	10.3
0.30	2.65	85%	3.9[3]	9.7

Notes:
[1] Defined as the ratio of ETAW to AW required for net deep percolation to equal natural drainage.
[2] Adequate leaching is not achieved. Soil salinity continues to rise over time.
[2] Very high distribution uniformity is required to achieve adequate leaching over entire field.

All of the drainage rates shown in the table require a high level of irrigation management to balance the need for leaching with the small amount of net deep percolation available through natural drainage. In fact, the modeling indicates that for a natural drainage rate of 0.25 foot/year, irrigation management is just able to maintain both leaching and shallow water table management, although the cost is high. At natural drainage rates of 0.20 foot/year or less, adequate leaching is not achieved and soil salinity deteriorates over time.

Figure G6-4 illustrates the effect on shallow groundwater salinity over time at different rates of natural drainage. Shallow groundwater is defined here as groundwater less than 20 feet below surface. The trend lines all start at 8,000 ppm of TDS and assume that land is kept in production. The analysis suggests that shallow groundwater salinity can be held reasonably constant at a natural drainage rate of 0.25 foot/year, assuming irrigation and cropping patterns are managed appropriately. This does not imply, however, that salt balance is achieved: salts continue to move downward and accumulate in the aquifer below 20 feet.



Qv = rate of natural drainage, in feet per year.

Figure G6-4 Sensitivity Analysis on Shallow Groundwater Salinity Under Different Conditions of Natural Drainage

G6.2.4 Drainage Service Alternatives

Differences among alternatives focus on disposal approaches. The two major alternatives configurations, Out-of-Valley Disposal and In-Valley Disposal, provide the same level of drainage service to the Unit. Their potential impacts on agricultural production and economics differ only because of the irrigated land converted for use by the treatment, disposal, and conveyance facilities. Importantly, both configurations incorporate the same assumptions for source control.

G6.2.4.1 Northerly Districts Subarea (San Luis Unit portion of the Grassland Drainage Area)

Key Assumptions

As a result, the analysis of impacts is almost identical for the alternatives. The only difference is the number of acres over which to aggregate impacts. Results below are described once, but apply to all of the drainage service alternatives. The important analytical comparisons occur between the No Action Alternative and any of the action alternatives.

The following common assumptions of analysis for the drainage service alternatives are used:

- Drainage service will be provided to the existing drained lands within the Unit districts, and additional drains will be installed as needed over time. By 2050, a total of 36,000 acres within the northern Unit districts will have subsurface drains installed. For purposes of analysis, new drains are assumed to be installed at a constant annual rate beginning in year 5 of the Plan.

- Drainage collected from fields will be 0.6 AF/drained acre, with 0.12 AF/drained acre recycled within the drained area. For analysis, the drainwater is assumed to be recycled on all lands within the drainage-affected area, not just lands with installed drains. This assumption results in 0.087 AF of drainwater/acre irrigated within the drainage-affected area.
- All drained lands (including 18,000 acres outside the Unit) will be served by drainage treatment and disposal facilities constructed as part of this Plan. All drainage not recycled will be delivered to a drainage re-use facility to provide irrigation for salt-tolerant crops. The re-use facility will reduce the volume of drainage by almost 75 percent: four AF of drainwater will be applied as irrigation on each acre in the re-use facility, with 1.08 AF/acre of drainage collected for further treatment and disposal.
- No groundwater is pumped and used for irrigation within the drainage-affected lands of the northern Unit. All irrigation water is provided from surface supplies or from the small amount of drainwater recycled within the drained area.
- No explicit costs for drainage service are assessed as part of this analysis. A separate evaluation of costs, payment capacity, and net benefits from drainage service will be completed.

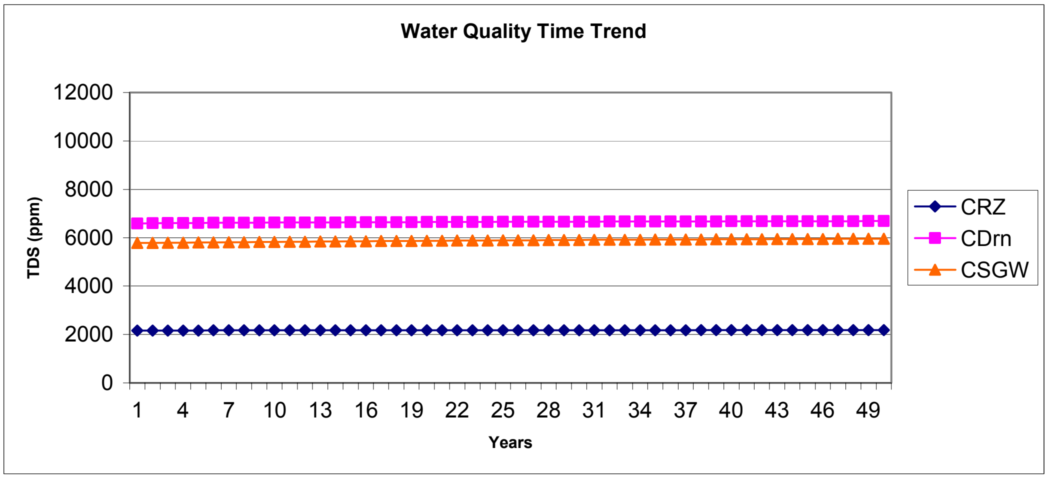
Results

Drainage service provided to the Northerly Districts subarea under any of the action alternatives results in relatively stable drainage and salinity conditions over the 50-year planning horizon. Figure G6-5 displays the estimated average soil, drainage, and shallow groundwater salinity for drained fields in this subarea.

Soil salinity is estimated to be stable at an average EC of about 3.1 dS/m. Virtually all crops except the most salt-sensitive trees, vines, and row crops can be grown under these conditions. Because this is an estimate of average salinity, some lands can likely be maintained at lower salinity, allowing an even wider range of crops. Undrained lands within the drainage-affected area are also estimated to have relatively stable, though somewhat higher, soil salinity. Overall seasonal water application efficiency in the Northerly Districts subarea is projected to average about 73 percent, although specific estimates can vary significantly across districts, crops, and growing conditions.

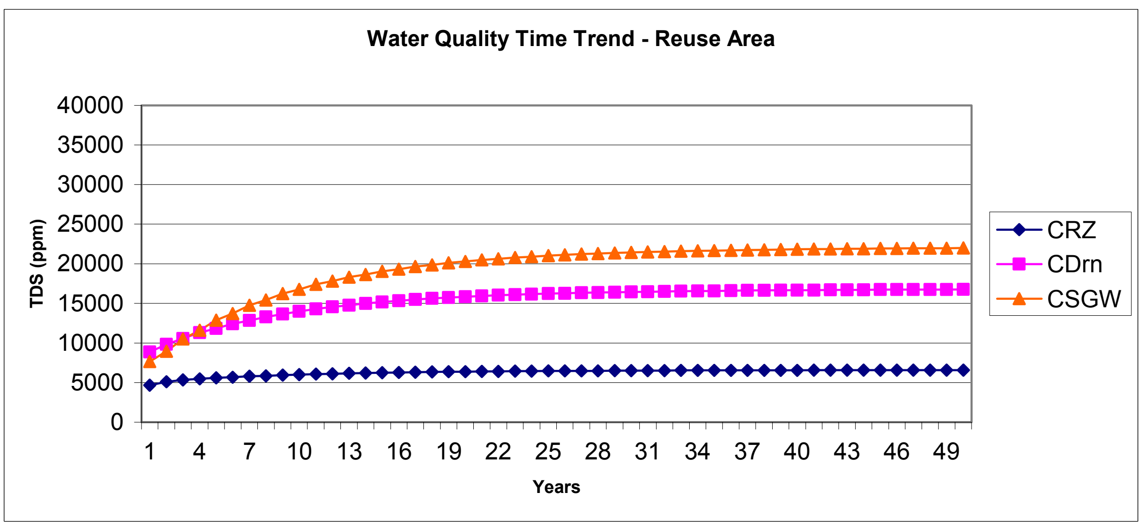
Under all of the drainage service alternatives, drainage collected from drained farmlands is conveyed to a regional Reuse Facility. The primary drainage is used to irrigate a salt-tolerant crop, and the drainage from the reuse facility is collected for further treatment and disposal. The reuse stage reduces the volume of drainage substantially and concentrates it. Figure G6-6 shows the trend in drainage, soil, and shallow groundwater salinity in the reuse facility. By 2050, the volume of drainwater collected from the reuse facility for further treatment and disposal is estimated to be about 9,500 AF/year, at about 16,750 ppm TDS. The annual trend in the volume and quality of drainwater collected from the facility is shown in Appendix I.

The soil salinity shown for later years in Figure G6-6 corresponds to an EC of about 8.5 dS/m. Very salt-tolerant crops must be used to provide sufficient water use under such saline conditions.



CRZ = Concentration of salts in the root zone (ppm TDS of saturation extract)
CDrn = Concentration of salts in drainwater or potential drainwater (ppm TDS)
CSGW = Concentration of salts in shallow groundwater (ppm TDS)

Figure G6-5 Salinity Trends in the Northerly Districts Subarea All Drainage Service Alternatives



CRZ = Concentration of salts in the root zone (ppm TDS of saturation extract)
CDrn = Concentration of salts in drainwater or potential drainwater (ppm TDS)
CSGW = Concentration of salts in shallow groundwater (ppm TDS)

Figure G6-6 Salinity Trends in the Northerly District Subarea Reuse Facility, All Drainage Service Alternatives

Appendix I includes a table of estimated drained acres, drainage volume, and drainage quality over a 50-year horizon. Only subsurface drainage collected from field tiles is shown. For each of the two drainage service configurations (In-Valley and Out-of-Valley), the amount collected from agricultural fields and that collected from the regional reuse facilities are shown.

Appendix I includes a table of estimated drained acres, drainage volume, and drainage quality over a 50-year horizon. Only subsurface drainage collected from field tiles is shown. For each of

the two drainage service configurations (In-Valley and Out-of-Valley), the amount collected from agricultural fields and that collected from the regional reuse facilities are shown.

G6.2.4.2 Westlands Water District

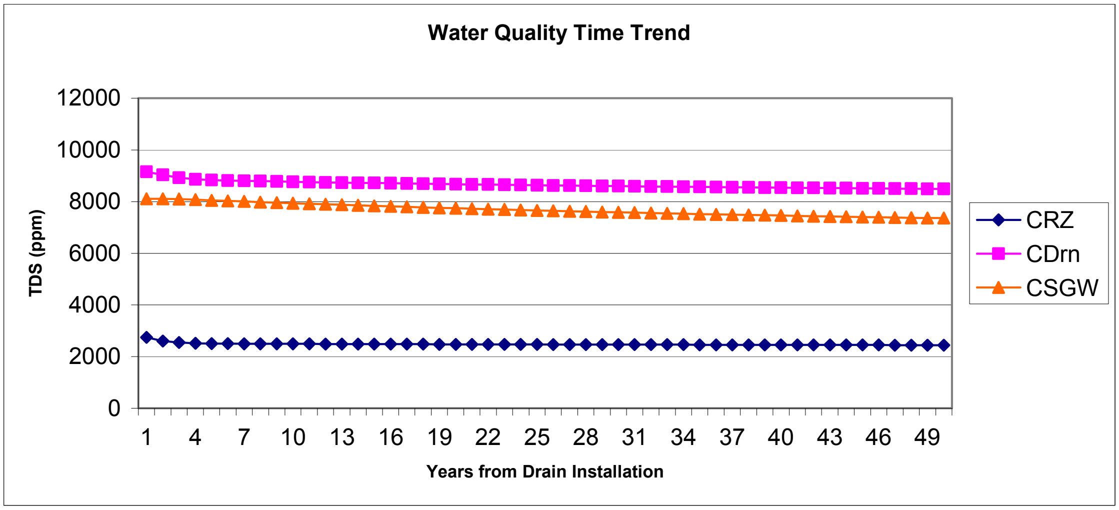
Key Assumptions

Many of the assumptions described below apply to all three of the subareas. Where differences exist, those are noted. For all alternatives, the following assumptions are used:

- Drainage service will be provided to a total of 187,660 acres in the Out-of-Valley Alternative. The In-Valley Alternative uses additional land for treatment and disposal facilities, resulting in a slightly lower 182,180 acres drained. For purposes of analysis, new drains are assumed to be installed at a constant annual rate beginning in year 5 of the Plan.
- Drainage collected from fields will be 0.5 AF/drained acre/year, with about 0.10 AF/drained acre recycled within the drained area. For analysis, the drainwater is assumed to be recycled on all lands within the drainage-affected area, not just lands with installed drains. In the initial years after drain installation begins, this assumption results in 0.002 AF of drainwater/acre irrigated within the drainage-affected area. By the time full drain construction is complete, about 0.04 AF/year of recycled drainwater will be applied per irrigated acre.
- All drained lands will be served by drainage treatment and disposal facilities constructed as part of this Plan. All drainage not recycled will be delivered to a drainage re-use facility to provide irrigation for salt-tolerant crops. The re-use facility will reduce the volume of drainage by almost 75 percent: 4 AF of drainwater will be applied as irrigation on each acre in the re-use facility, with 1.08 AF/acre of drainage collected for further treatment and disposal.
- Irrigation water in the drainage-affected area is a mix of surface supplies and groundwater. The mix can vary considerably between fields or farms, from year to year, and even within the year. For purposes of analyzing the long-term trends in salinity, irrigation water is assumed to be 88 percent surface water and 12 percent groundwater. The resulting salinity of applied irrigation water is about 530 ppm TDS.
- No explicit costs for drainage service are assessed as part of this analysis. A separate evaluation of costs, payment capacity, and net benefits from drainage service will be completed.

Results

Drainage service provided to lands in the Westlands subareas under any of the action alternatives results in relatively rapid improvement in soil conditions and a more gradual improvement in shallow groundwater and drainage salinity. Figure G6-7 shows the trend in salinity conditions for a particular field following drain installation. The figure shows estimates for the Westlands North subarea; results are similar for the other two drainage-affected subareas in Westlands. Drainage service provided to the Westlands subareas under any of the action alternatives is scaled in over time. The overall drainage quantity and quality estimates are derived by identifying the acreage of new drain installation each year and then aggregating the overlapping series of quantity and quality estimates over the 50-year planning horizon.



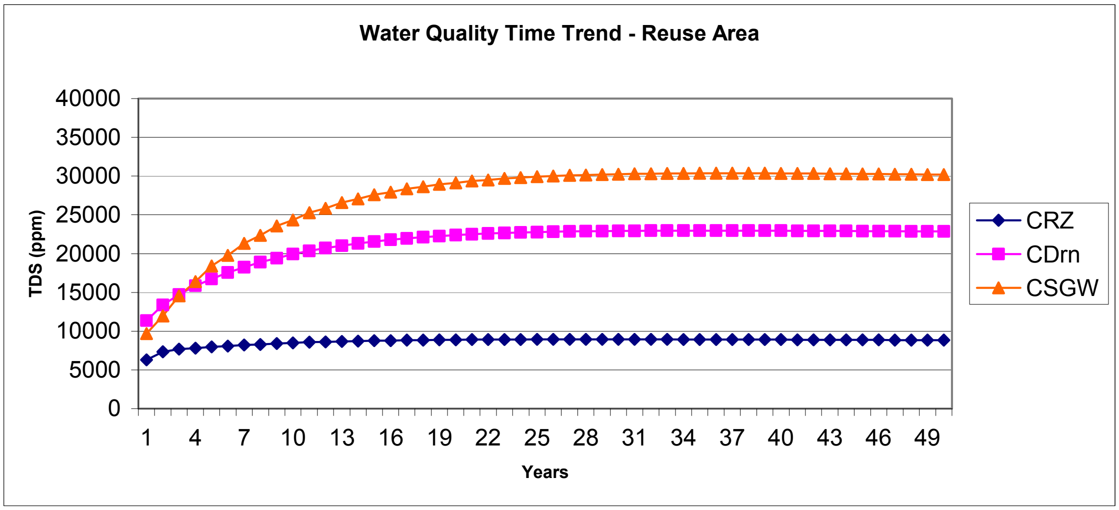
CRZ = Concentration of salts in the root zone (ppm TDS of saturation extract)
CDrn = Concentration of salts in drainwater or potential drainwater (ppm TDS)
CSGW = Concentration of salts in shallow groundwater (ppm TDS)

Figure G6-7 Salinity Trends for a Typical Drained Field in the Westlands North Subarea, All Drainage Service Alternatives

Soil salinity is estimated to be stable at an average EC of about 3.5 dS/m. Most crops except salt-sensitive trees, vines, and row crops can be grown under these conditions. Because this is an estimate of average salinity, some lands can likely be maintained at lower salinity, allowing an even wider range of crops. Undrained lands within the drainage-affected area are also estimated to have relatively stable, though somewhat higher, soil salinity. After all planned drainage installation, the overall seasonal water application efficiency in the Westlands North subarea is projected to average about 78 percent, though specific estimates can vary significantly across crops and growing conditions.

Under all of the action alternatives, drainage collected from drained farmlands is conveyed to a regional Reuse Facility. The primary drainage is used to irrigate a salt-tolerant crop, and the drainage from the reuse facility is collected for further treatment and disposal. The reuse stage reduces the volume of drainage substantially and concentrates it. Figure G6-8 shows the trend in drainage, soil, and shallow groundwater salinity in the reuse facility serving the Westlands North subarea (results for other Westlands reuse facilities would be similar). By 2050, the volume of drainwater collected from the reuse facility for further treatment and disposal is estimated to be about 6,500 AF/year, at over 22,800 ppm TDS. The annual trends in the volume and quality of drainwater collected from all of the reuse facilities are shown in Appendix I.

The soil salinity shown for later years on Figure G6-8 corresponds to an EC of about 11.5 dS/m. Very salt-tolerant crops must be used to provide sufficient water use under such saline conditions. Results for reuse facilities in the other Westlands subareas are similar, though the salinity levels are slightly lower.



CRZ = Concentration of salts in the root zone (ppm TDS of saturation extract)
CDrn = Concentration of salts in drainwater or potential drainwater (ppm TDS)
CSGW = Concentration of salts in shallow groundwater (ppm TDS)

Figure G6-8 Salinity Trends in the Westlands North Subarea Reuse Facility, All Drainage Service Alternatives

Appendix I includes a table of estimated drained acres, drainage volume, and drainage quality over a 50-year horizon for all of the subareas. Only subsurface drainage collected from field tiles is shown. For each of the two drainage service configurations (In-Valley and Out-of-Valley), the amount collected from agricultural fields and that collected from the regional reuse facilities are shown.

G6.2.5 Summary Comparison of No Action Alternative to Drainage Service Alternatives

G6.2.5.1 Objectives and Impact

The objectives of providing drainage service are to maintain long-term agricultural productivity and to reduce the accumulation of salts in the soil and groundwater. This section provides a summary of how the drainage service alternatives accomplish the objectives.

Soil salinity is measured as the EC of a soil saturation extract. EC provides an estimate of how crop yields may be affected by soil salinity, and therefore can be used to assess the cropping mix and flexibility possible under the alternatives. Table G6-4 illustrates the differences in soil salinity between alternatives and across regions. All of the changes from No Action to an action alternative are considered significantly beneficial to crop production.

Table G6-4
Average Soil Salinity Estimates for Drained Lands
(EC of saturation extract [dS/m])

Subarea	No Action Alternative	Drainage Service Alternatives
Northerly Districts	4.6	3.1
Westlands North	4.5	3.5
Westlands Central	4.5	3.5
Westlands South	4.4	3.5

Note: These estimates represent average or typical conditions, and assume careful irrigation and salt management (see irrigation cost estimates below). Some lands would have higher EC values, and some lands could be managed to maintain lower EC values.

Long-Term Salt Balance is defined for evaluation purposes as the net change in mass of salts in the root zone and shallow groundwater, relative to the No Action Alternative. Estimation focuses on a comparison of salts added in irrigation water to salts removed by drainage. The only salt removal occurring in the No Action Alternative is prior to 2009 in the Northerly Districts. For both the Out-of-Valley and In-Valley Disposal Alternatives, salt balance is significantly improved in all subareas. In all but one case the salt balance, as estimated here, is positive (net removal) by the year 2050 (Table G6-5).

Long-Term Yield Impacts are based on crop yield relationships formalized by Maas and Hoffman (see, for example, United Nations 1985). They estimated crop yield impacts caused by average soil salinity over the growing season. Table G6-6 summarizes the crops that are judged to be feasible to grow under the soil and drainage conditions provided by alternatives. A crop is judged feasible if its yield potential is at least 85 percent of what is considered normal for the San Joaquin Valley under nonsaline conditions. The crop changes suggested in Table G6-5 are based on average conditions in the drainage-affected area and, thus, should be viewed as illustrative of the direction of impacts. Some lands may be able to support moderately sensitive crops under appropriate management and crop rotation. Other lands may ultimately become infeasible to farm.

G6.2.5.2 Avoided Costs

The benefits of providing drainage service can be estimated as the reduction in production costs and revenue losses that would have to be incurred in the No Action Alternative. Three categories of avoided costs are considered here:

- Irrigation and salinity management costs that growers would incur by trying to farm under poorly drained and saline conditions
- The net revenue losses associated with lands retired under the No Action Alternative
- Net revenue losses resulting from growing a salinity-restricted crop mix

Table G6-5
Salt Balance Estimates for Drainage Service Alternatives
(tons of salt per year)

Year	Out-of--Valley Alternatives		In-Valley Alternatives	
	Salt in from Irrigation[1]	Salt out to Drainage[2]	Salt in from Irrigation[1]	Salt out to Drainage[2]
Northerly Districts				
2005	59,878	134,982	59,878	134,982
2030	59,878	197,748	59,878	197,748
2050	59,878	216,032	59,878	216,032
Westlands North				
2005	212,305	8,614	205,301	8,103
2030	212,305	125,151	205,301	117,734
2050	212,305	214,384	205,301	201,679
Westlands Central				
2005	165,207	8,246	163,639	8,101
2030	165,207	119,963	163,639	117,858
2050	165,207	207,088	163,639	203,455
Westlands South				
2005	168,890	6,865	168,145	6,800
2030	168,890	100,809	168,145	99,860
2050	168,890	175,205	168,145	173,557

Notes:
[1] Includes all irrigation water salts applied to the root zone, including salts in pumped groundwater; does not include salts from fertilizers and soil amendments.
[2] Additional salt migrates slowly out of the area through groundwater; has not been estimated.

The effects of poor drainage and salinity conditions can be partially and perhaps temporarily alleviated by more intensive irrigation management, but at a cost. When these costs exceed what growers are willing to pay, land will go out of production. The costs associated with higher irrigation management and lands going out of production in the No Action Alternative can be reduced if adequate drainage is provided. Table G6-7 displays estimates of the irrigation management costs needed under the No Action Alternative but that could be avoided by the drainage service alternatives. The **Irrigation and Salinity Management Costs Avoided** by Action alternatives increase over time as more land is provided drainage service. Dollar values are based on an update to the irrigation cost and performance study prepared for the Bureau of Reclamation under the San Joaquin Valley Drainage Program and the Unit Drainage Program (CH2M Hill 1994). Irrigation system performance estimates were compiled from studies

Table G6-6
Long-Term Yield Impacts of Soil Salinity in the Drainage-Affected Area

Subarea	Feasible Crops Under No Action	Feasible Crops With Drainage Service
Northerly Districts	Cotton, grains, sugar beets, other salt-tolerant field crops	Cotton, grains, sugar beets, alfalfa, tomatoes, most vegetables and field crops
Westlands North	Cotton, grains, sugar beets, other salt-tolerant field crops	Cotton, grains, sugar beets, alfalfa, tomatoes, most vegetables and field crops
Westlands Central	Cotton, grains, sugar beets, other salt-tolerant field crops	Cotton, grains, sugar beets, alfalfa, tomatoes, most vegetables and field crops
Westlands South	Cotton, grains, sugar beets, other salt-tolerant field crops	Cotton, grains, sugar beets, alfalfa, tomatoes, most vegetables and field crops

performed at California State Polytechnic University. The costs in Table G6-7 were derived by estimating the level of irrigation efficiency and distribution uniformity needed to maintain the net deep percolation within the small amount of natural drainage. Costs associated with higher levels of management include irrigation system hardware investment and operation and management costs. The estimates in the table represent the avoided cost in year 50 of the planing horizon.

Table G6-7
Irrigation and Salinity Management Costs Avoided Relative to the No Action Alternative (million $/year in 2050)

Subarea	Out-of-Valley Alternative	In-Valley Alternative
Northerly Districts	$6.0	$6.0
Westlands North	$10.8	$10.3
Westlands Central	$11.4	$11.3
Westlands South	$11.5	$11.4
Total	$39.8	$39.1

Note: Avoided costs increase over time. The estimates shown are as of the end of the planning horizon. In addition, these estimates assume the land stays in production. A further evaluation of whether some additional lands would be uneconomical under No Action is pending.

Even with the large increase in irrigation management costs, the overall salt balance within the drainage-affected area would continue to deteriorate. Over time, crops would shift toward a more salt-tolerant mix, and overall cropwater application would decline. The loss in net revenue will depend on how the mix of crops changes. Table G6-8 displays estimates of the aggregate loss in net revenue from farming. Crop mix with drainage service provided is assumed to be similar to overall crop mix in the Unit, with the exception that the most sensitive crops (orchards and vineyards) would not be planted in areas affected by shallow groundwater. The crop mix for the

No Action Alternative was assumed to shift to a mix of cotton, grains, and salt-tolerant field crops.

Prices and yields are based on Fresno County Agricultural Commissioner annual reports. Net revenues were estimated using crop-specific ratios of net revenue to gross revenue derived from the IMPLAN model for use in the Programmatic EIS, Central Valley Project Improvement Act (Reclamation 1997). (Estimates will be revised after completion and review of crop production cost budgets.)

Table G6-8
Cropping Pattern Changes: Net Revenue Losses Avoided Relative to the No Action Alternative (million $/year in 2050)

Subarea	Out-of-Valley Alternative	In-Valley Alternative
Northerly Districts	$1.9	$1.9
Westlands North	$2.0	$1.8
Westlands Central	$2.0	$1.9
Westlands South	$1.7	$1.6
Total	$7.6	$7.2

Note: Avoided losses increase over time as drainage is installed. The estimates shown are as of the end of the planning horizon.

The third category of cost avoided by drainage service alternatives is land retirement. Westlands has implemented a plan to spend $100,000,000 to retire 68,000 acres of drainage-affected land, which represents an upfront payment of about $1,470/acre to compensate participating growers for the lost net revenue from crop production. Under the No Action Alternative, this land is assumed to remain out of production for the 50-year planning horizon. The annual cost per acre is estimated by amortizing the initial cost over the 50-year horizon at 5.875 percent, resulting in a cost of about $92/acre/year to compensate growers for loss of net return.

The retirement plan explicitly allows for the land to come back into production as drainage service becomes available. The benefit (avoided cost) of bringing the land back is the estimated net return of $92/acre/year. This benefit increases over time as drainage is installed on retired land. For purposes of estimating benefits, retired land is assumed to be the first land to receive drainage service. No planned land retirement is assumed for the Northerly Districts.

The three categories of avoided costs are summarized in Table G6-9. Avoided costs are shown as the discounted present value over the 50-year planning horizon and as annual equivalent avoided costs. Most of the costs are avoided only as drainage service becomes available, and discounting them at 5.875 percent results in annual equivalent costs much lower than those shown in Tables G6-7 and G6-8.

Table G6-9
Summary of Costs Avoided Relative to the No Action Alternative
(Million $)

Avoided Cost Category	Out-of-Valley Alternative	In-Valley Alternative
Discounted Value of Avoided Costs		
Irrigation and Salinity Management	$195.86	$192.93
Cropping Pattern Changes	$24.58	$23.86
Land Retirement	$52.45	$51.76
Total	$272.89	$268.55
Annual Equivalent Avoided Cost		
Irrigation and Salinity Management	$12.21	$12.03
Cropping Pattern Changes	$1.53	$1.49
Land Retirement	$3.27	$3.22
Total	$17.01	$16.74

G6.3 REFERENCES

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